A Search for Neutrinoless Double-beta Decay of Germanium-76

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(on behalf of the MAJORANA Collaboration)
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The MAJORANA collaboration[1] is searching for neutrinoless double beta decay using ^{76}Ge, which has previously been shown to have a number of advantages in terms of sensitivities and backgrounds. The observation of neutrinoless double-beta decay would show that lepton number is violated, neutrinos are Majorana particles and provide information on neutrino mass. Attaining sensitivities for neutrino masses in the inverted hierarchy region, 25−50 meV, requires large, tonne scale detectors with extremely low backgrounds, at the level of 10^{-3} counts keV^{-1} kg^{-1} y^{-1} or lower in the region of the signal. The collaboration, with full funding support from DOE Office of Nuclear Physics and NSF Particle Astrophysics, is constructing the DEMONSTRATOR, an array consisting of 40 kg of p-type point contact germanium detectors, of which at least 30 kg will be enriched to 86% in ^{76}Ge. The DEMONSTRATOR is being built in a clean room laboratory facility at the 4850' level at the Sanford Underground Research Facility in Lead, SD. The primary aim of the DEMONSTRATOR is to show the feasibility for a future tonne scale measurement. If such a ^{76}Ge based measurement is found to be viable, the MAJORANA collaboration intends to join with the European based GERDA collaboration to pursue jointly building a tonne scale ^{76}Ge based array.

Neutrinoless double-beta decay ($0\nu\beta\beta$) is the only viable method to search for lepton number violation and correspondingly to determine the Dirac-Majorana nature of the neutrino[2, 3]. Reaching the neutrino mass scale associated with the inverted mass hierarchy, $25-50$ meV, will require a half-life sensitivity on the order of 10^{27} y, corresponding to a signal of a few counts or less per tonne-year in the $0\nu\beta\beta$ peak. To observe such a small signal, one will need to construct tonne scale detectors with backgrounds in the region of interest at or below ~ 1 counts t^{-1} y^{-1} (corresponding to 2.5×10^{-4} counts keV^{-1} kg^{-1} y^{-1}). A convincing discovery that neutrinos are Majorana particles and that lepton number is violated will require the observation of $0\nu\beta\beta$ in multiple experiments using different $0\nu\beta\beta$ isotopes.

The sensitivity of a $0\nu\beta\beta$ search increases with the exposure of the experiment, but ultimately depends on the achieved background level. This relationship is illustrated in Figure 1, where we have used the Feldman-Cousins definition of sensitivity in order to transition smoothly between the background-free and background-dominated regimes. Although this figure is drawn using experimental parameters relevant for $0\nu\beta\beta$ searches using ^{76}Ge, the situation for other isotopes is not qualitatively different. It may be concluded that achieving sensitivity to the entire parameter space for inverted-hierarchical MAJORANA neutrinos would require ∼10 tonne-years of exposure with a background rate of less than one count t^{-1} y^{-1}. Higher background levels would require significantly more mass to achieve the same sensitivity within a similar counting time.

The MAJORANA collaboration is searching for $0\nu\beta\beta$ using ^{76}Ge, which utilizes the demonstrated benefits of enriched high-purity germanium (HPGe) detectors such as intrinsically low-background source material, understood enrichment chemistry, excellent energy resolution, and the ability to apply sophisticated event reconstruction. The primary

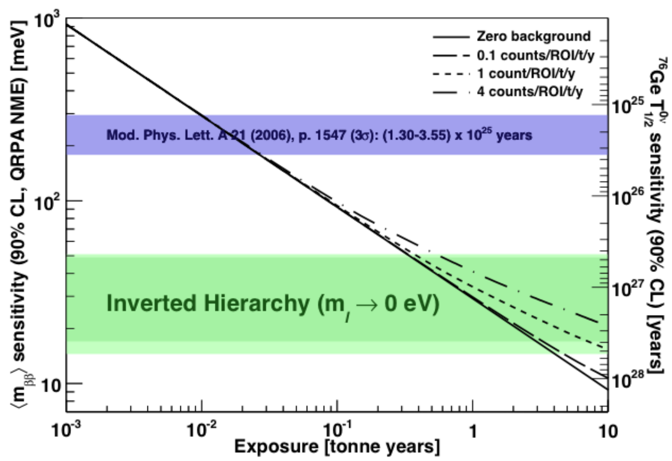

FIG. 1. 90% C.L. sensitivity as a function exposure for $0\nu\beta\beta$-decay searches in ^{76}Ge under different background scenarios. Matrix elements from [4] were used to convert half-life to neutrino mass. The blue band shows the region where a signal would be detected should the Klapdor-Kleingrothaus claim [5] be correct.

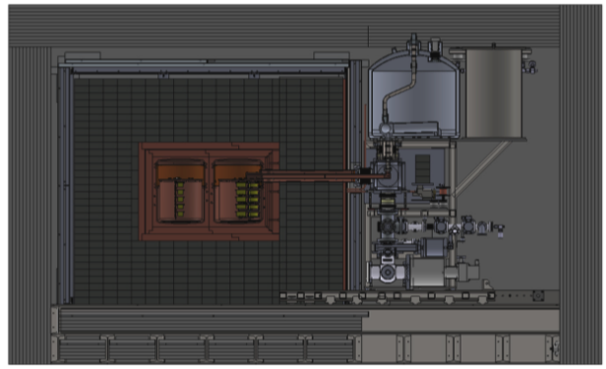

FIG. 2. Cross-sectional view of the MAJORANA DEMONSTRATOR. Strings of detectors are visible in the two cryostats. Cryostats are mounted in moveable transporters allowing independent assembly and testing before installation into the shield. The cryostat vacuum system and thermosyphon cooling system is visible for the cryostat on the right. For scale, the inner Cu dimensions where the cryostats are inserted is 20" high and 30" in length.

technical challenge is the reduction of environmental ionizing radiation backgrounds by about a factor 100 below what has been previously achieved. Specific goals of the MAJORANA DEMONSTRATOR are:

- Demonstrate a path forward to achieving a background rate at or below one count t^{-1} y^{-1} in the 4 keV region of interest (ROI) around the 2039 keV Q-value of the ^{76}Ge $0\nu\beta\beta$.
- Show technical and engineering scalability toward a tonne-scale instrument.
- Field an array that provides sufficient sensitivity to test the Klapdor-Kleingrothaus claim[5] while having comparable sensitivity with alternate approaches.

To this end, the collaboration is building the DEMONSTRATOR, a modular instrument composed of two cryostats built from ultra-pure electroformed copper, each of which can house over 20 kg of HPGe detectors [6–8]. The individual p-type point-contact (PPC) detectors have masses in the range of 0.6-1.0 kg. These PPC style detectors were chosen after extensive R&D by the collaboration. The baseline plan calls for two thirds of the detectors to be grown from 86% enriched material, resulting in a ^{76}Ge mass of 30 kg enriched detectors and 10 kg of natural detectors. This enriched material is sufficient to achieve the physics goal while still optimizing cost and providing a systematic check of enriched vs. natural Ge. The modular approach will allow us to assemble and optimize each cryostat independently, providing step-wise deployment with minimum interference on already operational detectors. The cryostats sit within a graded shield where the inner passive shield will be constructed of electroformed and commercial high-purity copper, surrounded by high-purity lead, which itself is surrounded by an active muon veto and neutron moderator (Figure 2). The experiment is currently being assembled in underground clean room laboratories at the 4850' level (1478 m) of the Sanford Underground Research Facility in Lead, South Dakota.

Cryostat 1, fabricated using ultra-clean electroformed Cu, will contain seven strings of both enriched and natural Ge detectors and is scheduled to be commissioned in late 2013. Cyostat 2, which will contain all enriched detectors, is scheduled to be be completed in 2014. The DEMONSTRATOR will be operated for about 3-4 years, in order to collect ∼100 kg-years of exposure. Based on a successful outcome, the collaboration plans to join with the GERDA collaboration to pursue a future tonne scale ^{76}Ge experiment. Construction of such an experiment would be carried out in a staged approach over a 5-8 year period, starting in 2016-2018. Total costs are estimated at $250 - $300M, and would be shared between international collaborators.

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